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HOUSING STRUCTURE AND CONTEXTUAL
INFLUENCES ON RESIDENTIAL
ENERGY CONSUMPTION

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PHILLIP NOWAK
AND
THOMAS KIRN

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CONTRA COSTA COUNTY PLANNING DEPARTMENT

HOUSING STRUCTURE AND CONTEXTUAL
INFLUENCES ON RESIDENTIAL
ENERGY CONSUMPTION

Phillip Nowak
and
Thomas Kirn

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I. Introduction

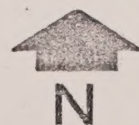
Previous studies of residential energy consumption have considered the effect of price (Houthakker, Verleger, and Sheehan, 1974; Nelson, 1975), climate (Strout, 1961), and time (Lockeretz, 1975). These studies implicitly accept energy demand as the collective outcome of consumer tastes and preferences in a free market context. However, in a period of potential energy shortfall, energy planners and local land use authorities are likely to devote increasing attention to non-price means of residential energy allocation. This paper examines residential electricity and natural gas consumption and their relationship to climate, housing structure and socioeconomic context. The attempt is to develop a tentative framework to evaluate the impact of conservation programs, future land use patterns and other non-price factors on expected residential energy consumption.

The paper is based on data for the years 1960, 1970, and 1975. The Study Area is Contra Costa County, California (Figure 1), a diverse economic and climatic area, which is located at the eastern edge of San Francisco Bay and extends inland to California's Central Valley.

The primary analytical techniques employed in the study are multiple regression and simple correlation. These techniques are applicable to any jurisdiction for which appropriate data is available. Results of the



FIGURE 1 ENERGY CONSUMPTION STUDY AREA : Contra Costa County



analysis support hypotheses that climate, housing structure, and certain socioeconomic factors are significantly related to the level of residential energy consumption.

II. Methodology

Simple correlation and multiple regression analyses were used to determine the relationship between residential energy consumption and selected structure context variables. Simple correlations measure the strength of association between pairs of variables. Multiple regressions may be used to estimate current or future energy consumption using several independent variables. Together, these techniques provide an analytical framework which is applicable to any jurisdiction for which appropriate data is available.

Multiple regression equations and simple correlation coefficients were computed for the individual years 1960, 1970, and 1975, and as pooled time series-cross-sectional data. As Nelson (1975) has noted, the cross-sectional approach necessarily assumes that all consumers face the same market possibilities during a given period of time. This is a correct assumption regarding residential energy customers in the Study Area, as all its consumers purchase energy from the same source under the same price schedule.

Electricity and natural gas consumption are treated as separate variables in the regression analysis. While simple correlation indicates some substitution occurs between the two types of energy use ($r=0.69$, $p .001$), the distinction remained useful to test hypotheses concerning the strength of certain determinants of natural gas use independent of electricity consumption.

III. Sample Selection, Variables and Hypotheses

Sample Selection

The sample data covers each of the fifteen cities of Contra Costa County for the years 1960, 1970 and 1975.¹ The three years were selected since socioeconomic data was available directly from censuses of population conducted in each of the respective years. Socioeconomic data could have been derived for other years; however, since some of the data would have to be derived through interpolation or estimation, it was decided to thus confine the analysis.

Variables and Data

The variables used in the analysis include electricity and natural gas consumption levels, two climatic indices, and five socioeconomic variables. A description of the variables follows.

Energy Consumption

Residential Energy Consumption is defined in terms of average annual kilowatt hours (KWHR) of electricity and thousands of cubic feet (MCF) of natural gas. Consumption of both electricity and gas varied widely among cities in the Study Area in 1975. Annual KWHR ranged from 3,767 KWHR to 10,284 KWHR, with a mean of 6,574 KWHR. The 1975 mean KWHR consumption represented an increase of 97.9% over average 1960 KWHR consumption. Natural gas consumption also exhibited considerable variation among the cities in the Study Area. In 1975 the city with the lowest average consumed 87.5 MCF, in comparison to 190.8 MCF for the highest city. Mean 1975 consumption in the study area was 116.7 MCF, an 8.1% increase over the 1960 mean.

Heating Degree Days, Cooling Degree Days

Heating Degree Days and Cooling Degree Days are measures of climatic conditions. Heating Degree Days refers to the total time required to maintain a design interior temperature, usually 65 degrees Fahrenheit, during one year. Cooling Degree Days is the analogous measure of cooling energy. With respect to Heating Degree Days, the colder the climate the greater the implied energy use. In areas of warm summer temperatures, the greater the number of Cooling Degree Days or periods of time when air conditioning is required to maintain the design temperature. Thus,

positive correlations are hypothesized with respect to both measures of energy consumption. Heating Degree Days is expected to have a stronger association to energy consumption than Cooling Degree Days, since nearly all households have some type of space heating system. Major exogenous cooling capability is limited to air conditioned households.

Average Number of Persons Per Household

Computed as the ratio of total population to occupied housing units, the average number of persons per household is hypothesized to be positively correlated with energy consumption for two reasons: first, a greater number of persons per household reflects a larger physical structure; second, a larger number of persons per household is likely to require heating or cooling for a larger proportion of a given housing structure.

Percent Single Family Homes

A single family home is defined as a single unit housing structure physically separated from all other units. The variable used in the analysis expresses the number of single family homes in each city as a percent of its total number of housing units. Percent Single Family Homes is included as an independent variable in the regression equations under the hypothesis that single family homes are associated with a high level of energy consumption relative to multiple units. By this argument, the higher the proportion of single family homes in an area, the greater the energy consumption.

Median Age of Housing Stock

Median age of housing stock in the Study Area in 1975 was 16.1 years; in 1960 the median housing age was 11.4 years. The increase in median housing age of only 4.7 years between 1960-1975 reflects the substantial housing construction activity during the fifteen year period. Median age of housing is expected to have a negative correlation with energy consumption since older homes tended to be smaller than those constructed in the recently constructed subdivisions.

Median Number of Rooms Per Dwelling

Median number of rooms per dwelling is a measure of the structural size of residential housing units.² A strong positive correlation is hypothesized between median number of rooms and both types of residential energy consumption. The larger the number of rooms, the greater the demand for space heating, lighting, air conditioning and other energy uses.

Median Household Income

Median household income in constant (1967) dollars was included in the regressions under the hypothesis that it would have a positive correlation with average energy consumption. A positive correlation is expected due

to: 1) an accompanying positive relationship between income and size of house; and/or 2) larger number of home energy uses by affluent families. The probable positive relationship between median household income and size of house is evaluated by the simple correlation analysis discussed in Section IV of the paper.

IV. Tests and Results

A. Simple Correlation Analysis

The simple correlation matrix for the pooled cross-sectional data is displayed by Table 1. The individual correlation coefficients generally display the hypothesized signs. For both electricity and natural gas consumption, median family income has the strongest positive correlation among the independent variables. The simple correlation coefficients are $r = 0.81$ ($p < .001$) with electricity and $r = 0.82$ ($p < .001$) with natural gas. This finding confirms that increasing consumption energy is associated with progressively higher family income. As expected, there is an accompanying strong positive relationship between median household income and the median size of house ($r = 0.86$, $p < .001$). In other words, affluent households tend to occupy larger homes than those with relatively less income.

TABLE 1

RESIDENTIAL ENERGY CONSUMPTION AND SOCIOECONOMIC AND CLIMATIC CONTEXT
SIMPLE CORRELATION MATRIX FOR CONTRA COSTA COUNTY: 1960 - 1975

	Heating Degree Days H-D	Cooling Degree Days C-D	Average Age of Structure A-A	Percent Single Fam. House SF/H	Persons Per Household P-HH	Median Household Income M-I	Median Number of Rooms M-R	Average Annual Kilowatts KWHR	Average Annual Nat. Gas NATGAS
H-D	1.00								
C-D	-0.24*	1.00							
A-A	-0.22	-0.27*	1.00						
SF/H	0.17	0.01	-0.17	1.00					
P-HH	0.01	0.18	-0.42**	0.71***	1.00				
M-I	0.59***	-0.12	-0.21	0.05	0.08	1.00			
M-R	0.57***	0.08	-0.23	0.30*	0.30*	0.86***	1.00		
KWHRS	0.33*	0.16	-0.20	-0.11	0.08	0.81***	0.75***	1.00	
NATGAS	0.71***	-0.10	-0.39**	0.16	0.25*	0.82***	0.77***	0.69***	1.00

* Indicates $p < 0.1$

** Indicates $p < 0.01$

*** Indicates $p < 0.001$

SOURCES: U. S. Bureau of the Census 1960 and 1970; 1975 Special Countywide Census of Contra Costa County;
Pacific Gas and Electric Company.

A second strong positive correlation is found between energy consumption and the median number of rooms per house. The correlation coefficients are $r = 0.75$, $p < .001$) with electricity and 0.77 $p < .001$) with natural gas consumption. By comparison, the simple correlation coefficients between the energy consumption measures and average number of persons per household are insignificant. Between electricity consumption and household size, $r = 0.08$; between natural gas and household size, $r = 0.25$. These results distinguish occupancy (household population) from structure (median number of rooms) as each is related to energy consumption. Size of house has the strong positive statistical correlation with energy consumption.

The third strong influence on residential energy consumption is Heating Degree Days. Heating Degree Days is more strongly associated with natural gas ($r = 0.71$, $p < .001$) than with electricity ($r = 0.33$, $p < .1$). This finding is consistent with the dominant use of natural gas as a furnace heating fuel in the Study Area.

The fourth contextual factor displaying the expected relationship to energy consumption is median age of housing structure. The simple correlation coefficient is negative between median age of structure and natural gas ($r = -0.39$ $p < .01$), but statistically insignificant with

respect to electricity ($r = -0.20$). The relative strength of the negative coefficient for natural gas reflects the tendency for heating in progressively older homes to be provided by single "space heaters" or other small heating systems and involve limited energy consumption.

Since data for three different years was pooled to calculate the 1960-1975 matrix, we also computed simple correlation coefficients for each of the individual test years. This makes it possible to examine how relationships between variables have changed in time. The technique also indicates whether a consistent pattern in the relationship between two variables exists over time. Table 2 summarizes the correlation coefficients between energy consumption and the socioeconomic context variables for 1960, 1970 and 1975.

With one exception, results of the comparison of correlation changes exhibit a consistent pattern with respect to electrical energy consumption. That is, coefficients which increased from 1960 to 1970 also increased from 1970 to 1975, and those which decreased from 1960 to 1970 also decreased from 1970 to 1975. The magnitude of change in several of the coefficients is quite striking. For electricity consumption and median age of house, the respective coefficients are -0.25 in 1960, -0.63 ($p < .001$), and -0.72 ($p < .001$) in 1975. This pattern further confirms our hypothesis that age of

TABLE 2

SUMMARY OF CORRELATION CHANGES BETWEEN ENERGY CONSUMPTION
AND CONTEXT VARIABLES: 1960 - 1975

	<u>Simple Correlation with Kilowatt Consumption</u>			<u>Simple Correlation with Natural Gas Consumption</u>		
	<u>1960</u>	<u>1970</u>	<u>1975</u>	<u>1960</u>	<u>1970</u>	<u>1975</u>
Median Age of House	-0.25	-0.63***	-0.68***	-0.71***	-0.39*	-0.47*
Percent Single Family Homes	0.61***	0.51**	0.42*	0.57**	0.41*	0.25
Median Household Income	0.32	0.81***	0.83***	0.30	0.84***	0.94***
Average Number Persons Per Household	0.33	0.76***	<u>0.76***</u>	0.13	0.58***	0.80***
Median Number of Rooms	0.14	0.82***	<u>0.80***</u>	0.64***	0.77***	0.79***

* Indicates that $p < 0.1$

** Indicates that $p < 0.01$

*** Indicates that $p < 0.001$

structure has an inverse relationship to energy consumption over time. Further, it appears that this relationship has become increasingly significant. We may also note the relative importance of housing size in strengthening the positive correlation. It is clear that median number of rooms is an important factor in enhancing energy consumption: in 1960, $r = 0.14$; in 1975, $r = 0.80$. The possible energy impact of changes in construction standards or techniques in the Study Area remain a question for future research.

Among the other correlation coefficients, the relative strength of percent single family homes declined from .61 ($p < .001$, 1960), to 0.42 ($p < 0.1$, 1975). This change reflects the transition from single to multiple homes in several cities in the Study Area. Newer multiple housing units tend to be larger than older ones, and several areas in which single family homes predominate have small, older houses which consume relatively little energy.

Perhaps the most notable 1960-1975 correlation change is between energy consumption and median household income. Using inflation-adjusted income, the energy-household income correlation coefficient jumped from $r = 0.32$ ($p < 0.1$, 1960) to $r = 0.83$, $p < .001$, 1975). In part, this increase reflects the construction of numerous large homes subsequently occupied by high income families. The major

increase in the correlation coefficient occurred between 1960 and 1970, a primary development and home construction period in the Study Area.

Changes in correlation coefficients between natural gas consumption and socioeconomic variables generally parallel those for electricity consumption. As with electricity consumption, the natural gas - percent single family homes correlation decreased between 1960 ($r = 0.57$, $p < .001$) and 1975 ($r = 0.25$). The median income coefficient increased sharply, from 0.30 ($p < .1$) in 1960 to 0.94 ($p < .001$) in 1975. This change may reflect increased use of gas-heated home swimming pools among upper income families relative to other income groups. Natural gas prices have increased dramatically in the 1970's so that some expendible natural gas uses, e.g. swimming pools, are becoming concentrated among a smaller number of income groups.

Changes in the correlation between electric energy consumption and median number of rooms is the one inconsistency occurring between 1960 and 1975. The positive simple correlation coefficient was larger in 1975 than in 1960, but smaller than in 1970. In part, the explanation for the decrease may be our use of 1970 data in 1975. (See Footnote 2.) To the extent that there was an actual 1970-75

increase in median number of rooms paralleling per capita electric energy consumption, our use of 1970 housing data with 1975 consumption would weaken the computed correlation.

The one notable distinction between correlation changes for natural gas and for electricity concerns median age of house. As the negative correlation coefficient between electricity consumption and median age of house increased from a statistically insignificant -0.25 in 1960 to -0.68 ($p < .001$) in 1975, the analogous coefficient between natural gas and median age of house decreased from -0.71 ($p < .001$) in 1960 to -0.47 ($p < .01$) in 1975. We believe that the decreases in the natural gas - median age of house correlation between 1970-1975 involve the increased availability and use of natural gas in the Study Area, particularly between 1960 and 1970 when the population grew very rapidly. The net impact of the rapid growth of new homes fuelled by natural gas was to decrease the negative correlation between natural gas consumption and median age of the house.

The simple correlation analysis of individual years thus illustrates several significant relationships between energy consumption and socioeconomic context variables. There is an increasing positive association of household income, occupancy and structure with energy consumption in successive years. Negative correlations were

found between energy consumption and median age of house. The pattern and consistency of these results provided the foundation for the predictive regressions equations.

B. Regression Equations

Two regression equations were derived using the pooled time series crosssectional data. Equation (1) expresses average annual electricity consumption (KWHR) as a function of median income, cooling degree days, median number of rooms, and heating degree days. Equation (2) expresses average annual natural gas consumption (NATGAS) as a function of median income, heating degree days, and average number of persons per household. These variables are included in the equations because each satisfies the condition that its t-values be significant at $p = 0.05$ (two-tailed test) or better. T-values for the equations are shown in parentheses and the level of significance is noted.

$$(1) \text{ KWHRS} = +0.37 \text{ MEDINCOME} + 1.60 \text{ COOLDEG} - 36.76 \text{ SF/HOUSE} + 1156.90 \text{ MEDROOMS}$$

$$(3.18)^{***} \quad (3.09)^{***} \quad (-2.89)^{**} \quad (2.16)^{+}$$

$$r^2 = .77$$

$$f = 36.07, p < .001$$

$$(2) \text{ NATGAS} = -67.0 + .005\text{MEDINCOME} + .034\text{HEATDEG} + 11.63 (\text{PERS/HH})$$

(6.77)*** (4.15)*** (2.89)**

$$r^2 = .79$$

$$f = 36.07, p < .001$$

+ Indicates $p < .05$

** indicates $p < .01$

*** indicates $p < .001$

There are low simple correlations between the independent variables indicating that the ability of the equation to explain variance in energy consumption measures is not spuriously high due to one important index of multi-collinearity. Equations (1), $r^2 = .77$, and (2) $r^2 = .79$ indicate that roughly 80% of the variation in electricity and natural gas consumption is associated with the variables included in the respective equations.

Similar interpretations follow from both of the equations. A given level of income or a change in income may be expected to have a greater impact on electricity use than on natural gas use. Median number of rooms has the largest unit impact on electricity use ($b = 1156.9$, $p < .05$). An increase of one room adds over 1,150 KWHRS of average annual electricity consumption. Unit changes in average number of persons per household, the measure of occupancy, have the largest impact on natural gas consumption. One additional person per household will on the average increase natural gas consumption by 11.63 thousand cubic feet.

A substantial impact of heating degree days on natural gas consumption and cooling degree days on electricity consumption is indicated by the regression coefficients. For each reduction of 1.6 cooling degree days, the

number of kilowatts consumed should drop by 1.0. The local climate conditions implied by degree days are not subject directly to public policies toward energy consumption. However, a linkage between climate and a policy variable is provided by the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE). ASHRAE has developed construction standards for maximum permissible thermal transmittance values for a given geographic area according to number of heating degree days and type of structure.³ Changes in thermal transmittance value of U values through alternative building insulation, building design, or exposure is mathematically equivalent to reducing the heating degree (or cooling degree) days.⁴ Implied reductions in degree days and the effect on energy consumption may thus be evaluated using the regression equations.

With respect to single family homes, the coefficient of -36.8 ($p < 0.01$) implies that electricity consumption declines 36.8 KWHRS for each 1% relative increase in single family homes in an area. This result appears puzzling in light of the strong positive simple correlation coefficients between energy consumption and percent single family for individual years. However, over time, several cities in the Study Area have retained a high proportion of small, low-energy consuming single family homes. Other cities have experienced development of large multiple units so that the positive relationship between energy consumption and single family homes has been "diluted".

V. SUMMARY AND CONCLUSIONS

The study sought to determine key variables influencing the pattern of current residential energy consumption in a geographic area having diverse climatic, socioeconomic, and energy consumption patterns. The intent was also to develop a framework to allow prediction of future consumption by determining the magnitude and direction of influence by selected variables. Simple correlations and regressions confirm the importance of climate, income and structure as significant positive influences on both types of energy consumption. These findings suggest opportunities for local public policies to encourage substantial reductions in residential energy consumption.

The public policy implication of the relationship between climate and energy consumption involves measures to mitigate the consumption effect of climatic conditions. Alternative insulation and structural design changes may have substantial impact on reducing energy consumption. Insulation or design standards for new residential housing can be evaluated by examining the degree of mitigation and assigning dollar values to the change in energy consumption.

We also noted that a reduction of approximately 1150 KWHRs annually is implied by one less room per housing unit. When considered along with the positive correlation between percent of single family homes in an area and

average electricity consumption, the impact of structure is confirmed. In the context of consumer preference for single family homes, the general implication of this finding is that smaller single family and multiple housing units should be encouraged. An average reduction of one room per unit in a new housing development is perhaps the most immediate nonprice means of achieving voluntary reductions in residential consumption.

Tentative policy ideas to provide incentives for construction of smaller housing units include land use planning (maximum parcel sizes) and local fiscal policy ("bedroom taxes"). In addition, the continuing trend toward smaller families and increasing home purchase and operating costs may provide exogenous impetus away from large single family housing units. Further research of both the study findings and exogenous factors will thus be necessary to specify alternative means to reduce residential energy consumption. This study has identified certain factors which provide the potential for effective nonprice energy policy formulation.

FOOTNOTES

¹Not all of the cities in the Study Area were incorporated prior to 1970 and energy consumption data was not available. Mean per capita consumption data for the total Study Area was used in these cases.

²Median number of rooms per dwelling is reported by the 1960 and 1970 U.S. Censuses. A Special 1975 Census of the Study Area reported the mean number of bedrooms. Rather than adjust 1975 data to estimate median number of rooms we used 1970 data. The correlation between 1970 rooms and 1975 bedrooms is $r=0.93$ ($p .001$).

³The thermal transmittance or U value for a given structure is expressed mathematically as the ratio of thermal transmittance, U_i for Area_i to total exterior area A:

$$U_o = \frac{U_{\text{wall}} A_{\text{wall}} + U_{\text{window}} A_{\text{window}} + U_{\text{door}} A_{\text{door}}}{A_o}$$

⁴The Contra Costa County Planning Department recently initiated a policy of reviewing the potential reduction of energy consumption in proposed subdivisions by maximizing north-south orientation of the housing units.

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